International Journal of Sustainable Built Environment (2015) 4, 189–201

HOSTED BY
ELSEVIER

Gulf Organisation for Research and Development

International Journal of Sustainable Built Environment

ScienceDirect
www.sciencedirect.com

Original Article/Research

Monitoring results of CO_2 avoidance with an 8.5 kWh solar electric generator integrated in a high rise commercial building in UK

Chukwuemeka Uchenna Ikedi [a,b,*], Michael I. Okoroh [a]

[a] School of Engineering and Technology, University of Derby, Markeaton Street, Derby, UK
[b] Energy Commission of Nigeria, Nigeria

Received 13 February 2014; accepted 1 October 2015

Abstract

Sustainable energy technologies have become very attractive and effective at the moment for use in the UK and other parts of the world as techniques for reducing carbon footprints in the building sectors. These include micro-wind turbines, photovoltaics, small hydro power generators and bio-tech systems. Besides building integrated solar electric generators otherwise referred to as building integrated photovoltaics (BIPV), which is aesthetically appealing and forms part of the applied building fabrics, most other options could deform the building aesthetics and require large spaces for both installation and operation especially, the wind turbine. These advantages and more make BIPV one of the most attractive sustainable energy technologies in contemporary building sectors at the moment. The technology involves the integration of photovoltaics (PV) modules into the fabric and shell of buildings like the roofs, asphalt shingles, facade materials and shading elements. Used in this way the integrated PV modules could replace conventional building materials thereby benefiting from improved capital cost and reduction of carbon footprint in the applied environment. However, one major lapse identified with previous studies had been the unavailability of numerical methods and quantification of the CO_2 mitigated by applied low carbon technologies.

Using a parametric method with the aid of Kyoto platform software integrated into a state of the art SMA data technology, this paper assesses and quantifies the CO_2 avoidance by a building integrated solar electric system applied in a business/commercial building in the UK.

The CO_2 protection capacity of the solar electric system has been confirmed to be influenced by the different seasons of the year providing maximum environmental protection in the summer months.

Keywords: Building integrated solar electric generators; CO_2 avoidance; Commercial buildings

1. Introduction

Any process that imposes or reduces cost or value in the built environment, especially on existing residential and commercial buildings, requires a continuous assessment of the impact of its application. This becomes inevitably necessary in order to keep in check, factors which affect the health and safety of the environment. One of such processes is the installation and use of sustainable energy technologies in residential and commercial/office buildings with a primary aim to cut down carbon footprints and provide a safer and healthier living and working environment. Statistics have shown that commercial/office buildings

* Corresponding author at: School of Engineering and Technology, University of Derby, Markeaton Street, Derby, UK.
Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2015.10.003

alone, account for 20% of the carbon dioxide (CO_2) emissions in the UK (Barlow and Fiala, 2007), and with the UK's existing building stock being replaced at a rate of 1–1.5% per annum (Perez-Lombard et al., 2007), occupants of existing offices will need to respond to rising temperatures resulting from climate change with the possibility of temperatures exceeding comfort levels by as many as three to five working days by 2050 (Ackerman and Stanton, 2006).

It becomes obvious therefore that the position of commercial/office buildings in strategies towards achieving a healthy and secured built environment cannot be over emphasised.

Several sustainable energy technologies exist at the moment as options for reducing carbon footprints in the built environment which include micro wind turbines, building integrated photovoltaic (BIPV), combined heat and power (CHP), small hydro power generators and bio-tech units.

Personal observations has shown that space is a critical issue with high density commercialised urban areas making building integrated solar electric generators (BIPV), a convenient and efficient technology for application in such urban settings.

Also as trade and commerce has implied that most commercial and office buildings are found or situated in the urban areas, it has generally been recognised that BIPV which is applicable on commercial/office building envelopes (Omer et al., 2003) has the capability of being a major source of sustainable energy in the urban areas (Tian et al., 2008).

One key benefit in the application of BIPV technology on commercial and office buildings is sustainability and according to Davies (2005); "sustainable commercial buildings perform better than conventional commercial buildings in terms of wellbeing of the occupants, building value and return on investment".

Research has also shown that 70% of 200 large firms surveyed in the UK would be attracted to sustainable commercial/office buildings designed to minimise environmental impact of CO_2 as compared to conventional existing commercial/office buildings.

In addition to providing sustainable zero-carbon electrical power to an office building, innovations in PV modules can now provide natural day lighting effects in office settings as sky lighting devices (Wonga et al., 2008), adding extra illumination and beauty to modern office architecture. Replacement of the conventional building materials improves the payback period of the technology as well as the life-cycle cost of the buildings.

This thesis has identified the need to assess and quantify the capacity of integrated solar electric generators based on an office/commercial high rise building in the UK. The outcome of the assessments could then be used to quantify and justify the environment impact of the technology as a sustainable energy project investment.

2. Case study (University of Derby UK)

University of Derby, Kedleston campus is located in the Derby city which is at the south east part of Derbyshire in the East Midlands of the UK. The meteorological conditions include a latitude of 52 deg 56′20″N and longitude of 01 deg 29′47″W, obtainable at the site of the University of Derby with a typical average temperature of about 4 °C in winter and about 18 °C in summer.

The Kedleston campus building has a total area of 7733 m^2 at the east wing, 5988 m^2 at the north wing and 4645 m^2 at the south wing suitable for solar installations. All these receive direct beam solar radiation, though some only for limited periods of the day. Part of these roof spaces by the main entrance wing of the building has been reserved and used for nine electric wind turbine generators, while the roof area on the old administration block at the north wing of the building was used for the PV integration. The building, which provides office and educational space for most staff and students of the University, is a three – winged nine storey high rise building with transparent roofed atriums as sky lights to support day time illumination at the central area of the building and ventilation aiding designs and devices. The BIPV system is used to offset part of the building's electrical demand.

In terms of occupancy pattern, the Kedleston campus building involves a unitary occupancy pattern which implies occupancy by only the staff and students of the University and affiliated outfits.

This means that decisions regarding the planning, design and implementation of projects on the building and its premises are within the domain of the University management. The department charged with decisions on both the feasibility and implementation of the BIPV project meant for this research case study is the Estate and facilities management department of the University. The occupancy pattern in the University building also complies with the definition of commercial occupancy in the sense that the major activity in the building is of a commercial nature as compared to residential settings.

For instance, major activities in the building occur within the conventional office hours, between morning hours and evening. A graphical representation of the energy and other utility use in the building will therefore show a rise and peak form within this time interval, while the later hours of the days will show a significant drop in the graph.

Figs. 1.0 and 2.0 below, show a pictorial and layout view of the University of Derby, Kedleston campus respectively.

From the layout diagram above (Fig. 2.0), there is a relatively good solar line of site at the campus site. The diagram shows schematic images of trees within the premises. However, these trees as shown in the diagram are distantly located away from the building structures. Some of the trees which would have coincided with the solar line of site are found to be shorter in height than parts of the building containing the BIPV array devices.

Fig. 1.0. Side view of the main research project site (University of Derby).

Furthermore, being located at a latitude of 52 deg. 56′20″N and longitude of 01 deg 29′47″W, the average total daily solar radiation which can be received by a solar panel tilted at an inclination approximate to the latitude is about 1100 kW/m^2/day.

3. Methodology

A one year monitoring was conducted to assess and quantify the CO_2 mitigated by the integrated solar electric generator on the applied building. This was followed by a parametric evaluation which is purely analytical and involves logic based mathematical and photovoltaics engineering methods to analyse different sets of parameters acquired from the one year monitoring in the study. The parametric study consists of two parts namely, parameters and tasks. The parameters include sets of values which were directly monitored and measured from the BIPV systems while the tasks imply the procedures used in the environmental impact assessments, describing how the parametric analysis was carried out. One major barrier identified in this aspect of the study was how to gather and apply observable and measurable data associated with the system in such a way as to aid existing owners and potential investors decide whether the technology provides appropriate environmental protection to the applied environment. Approximate values of the CO_2 avoidance (kg) were graphically generated and evaluated in such a way as to measure the amount of carbon omitted or mitigated by the use of the technology against fossil fuels in grid electricity generation.

The measurement for the CO_2 avoidance in the work is based on two factors namely: the conventional fuels used in the UK power stations and the CO_2 factor. The CO_2 factor measured in kg/kWh is an indication of how much CO_2 is produced for every one kilowatt hour of electricity produced by fossil fuels in power stations/generators.

This factor could vary between various energy supply companies. However, the monitoring equipment used in this study is based on the standard UK calibration.

In general, the method for calculating the CO_2 avoidance is as follows:

$$\text{Generated electricity (kWh)} \times CO_2 \text{ factor (kg/kWh)} = CO_2 \text{ avoidance (kg)} \tag{1.1}$$

The generated graphs for CO_2 avoidance was monitored on a daily basis and this was carried out for one year in order to account for the different seasons of the year namely: winter and summer. The monitoring was commenced from July 2010 to July 2011. However, for simplicity and assessment purposes, the data were subsequently compressed to monthly average values for the different months of the year. Finally, the graphical representations of the data were applied to deduce and assess the environmental impact or protection of the applied solar electric generator. The results of the graphical data and the subsequent assessment results are presented in Sections 4 and 5 respectively.

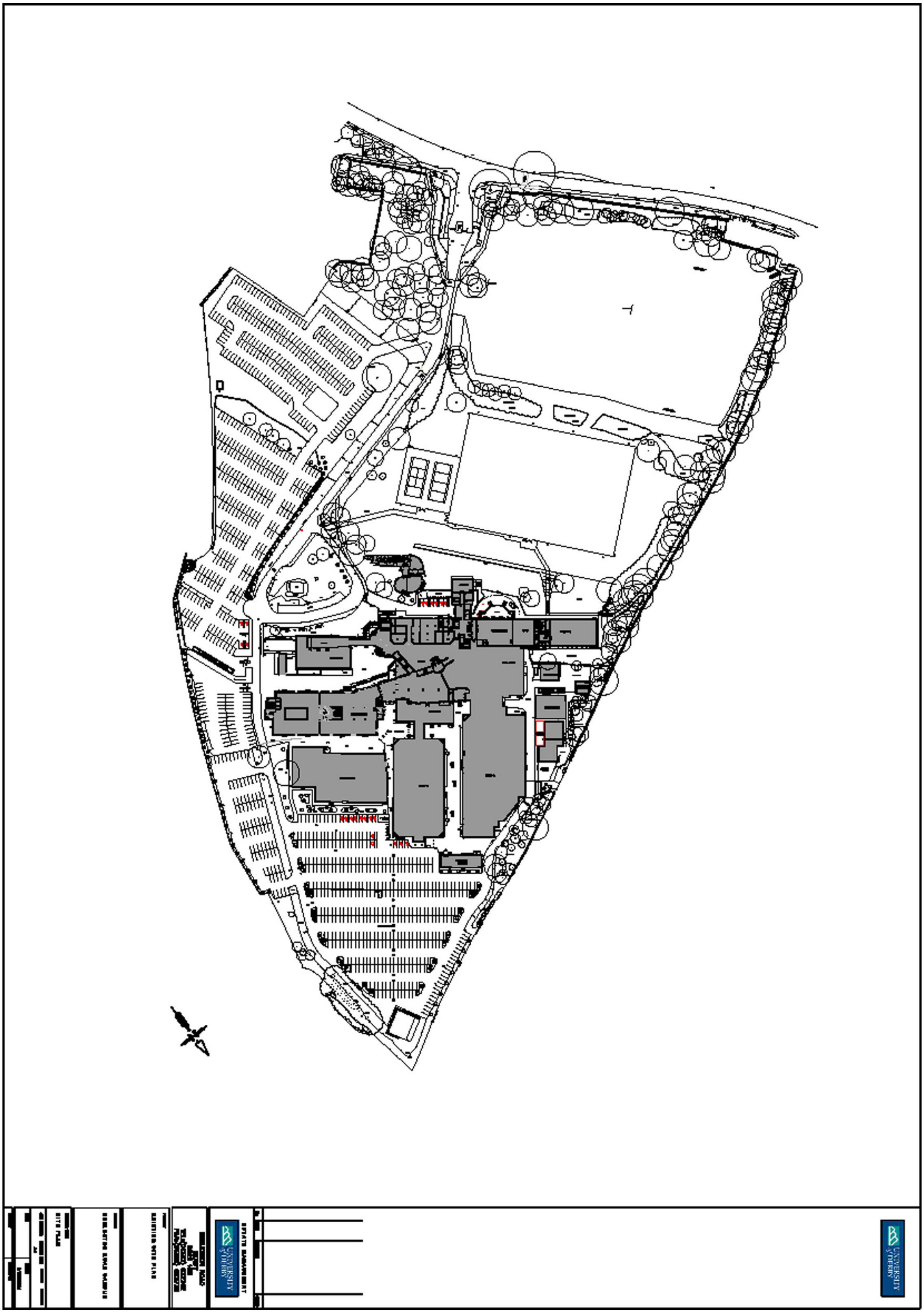

Fig. 2.0. Aerial layout of the BIPV project site (University of Derby).

4. Monitoring results: daily CO_2 avoidance

The CO_2 avoidance graph (Figs. 3.1–3.13) below is a measure of the contribution of the system to climatic and environmental protection in the mitigation or avoidance of greenhouse and carbon dioxide emissions during the generation of equivalent amount of electrical power via burning of fossil fuels in the grid power station which supplies the applied building.

Based on the calibration format for the CO_2 factor in the SMA data monitoring equipment used for the study, the following graphical results were generated for the different months of the monitoring period between the 1st of July 2010 and 31st of July 2011 (Figs. 3.1–3.13).

5. Discussion of the results

The graphical results (Figs. 3.1–3.13) are measurements based on intrinsic calibrations of two factors namely: the conventional fuels used in the UK power stations and the CO_2 factor which is a measure of how much CO_2 is released for every one kilowatt hour of electricity produced by fossil fuels in power stations/generators.

The results which are daily readings were taken for each day of the months from the 1st of July 2010 to 31st of July 2011.

The characteristic patterns of the graphs in the results can be explained with respect to different seasons of the year and these patterns have a direct relationship with the amount of solar radiation available on each day at the project site.

Figs. 3.11–3.13 show the quantities of CO_2 mitigated or avoided daily as a result of the use of the BIPV system in the summer months of May, June and July 2011 while Figs. 3.5–3.7 show the daily values in the winter months of November 2010, December 2010 and January 2011. On good clear sunny summer days when the BIPV panels locate direct solar radiations, the power generation capacity as well as the total energy yield of the system increases thereby maximising the avoided CO_2 for every one kilowatt hour of electricity produced by the system. From the graphical results (Figs. 3.11–3.13), the maximum daily CO_2 avoidance recorded in the summer months are as follows: about 94 Kg on the 1st and 2nd of May 2011, 102 kg on the 3rd of June 2011 and 98 kg on the 24th of July 2011. The winter months (Figs. 3.5–3.7) recorded corresponding maximum daily CO_2 avoidance of about 29 kg on the 6th of November 2010, 16 kg on the 25th of December 2010 and 23.5 kg on the 20th of January 2011.

The significant difference observed in the maximum capacities of the system to reduce daily CO_2 at the months of the different seasons is explained based on the direct relationship between the system's performance and solar radiation at different seasons. Summer seasons are characterised by clear climatic solar conditions which enhanced direct incident solar radiation on the solar panels, consequently maximising the power generation and CO_2 avoidance capacity of the system. The winter season on the other hand is characterised by cloudy climatic conditions, resulting in diffuse solar radiations which retard or impede the power generation and CO_2 avoidance capacity of the system.

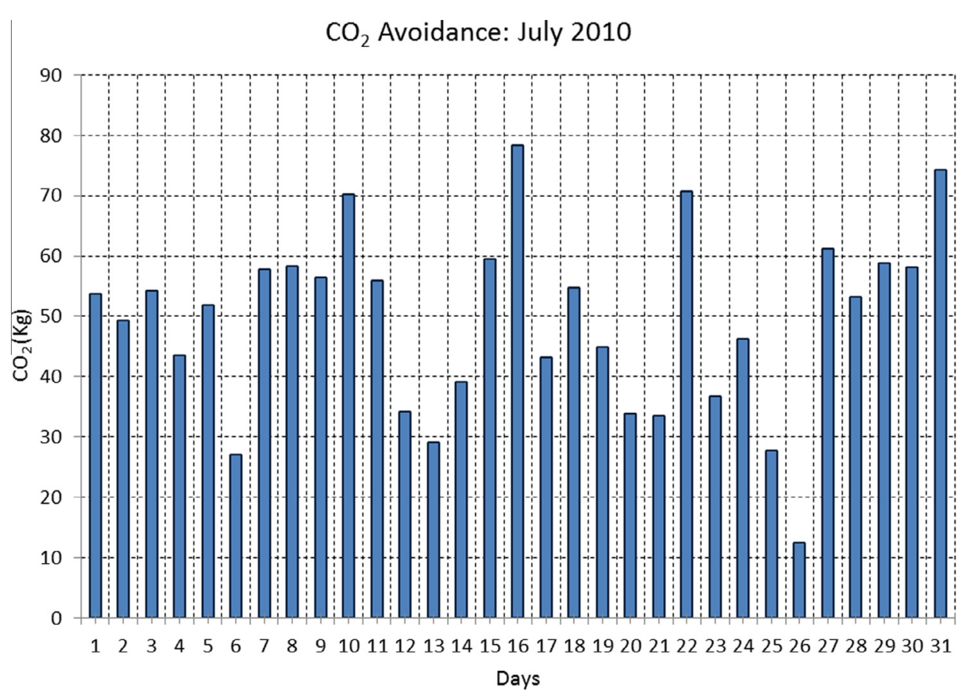

Fig. 3.1. CO_2 avoidance – July 2010.

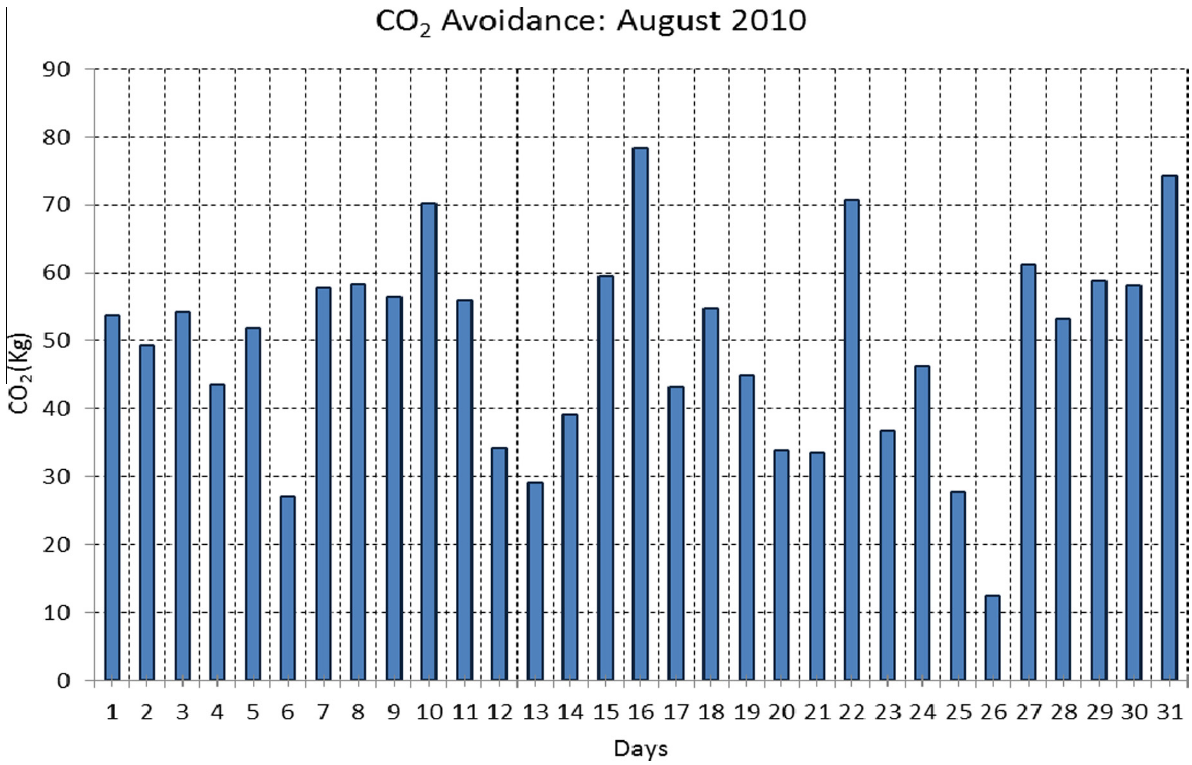

Fig. 3.2. CO_2 avoidance – August 2010.

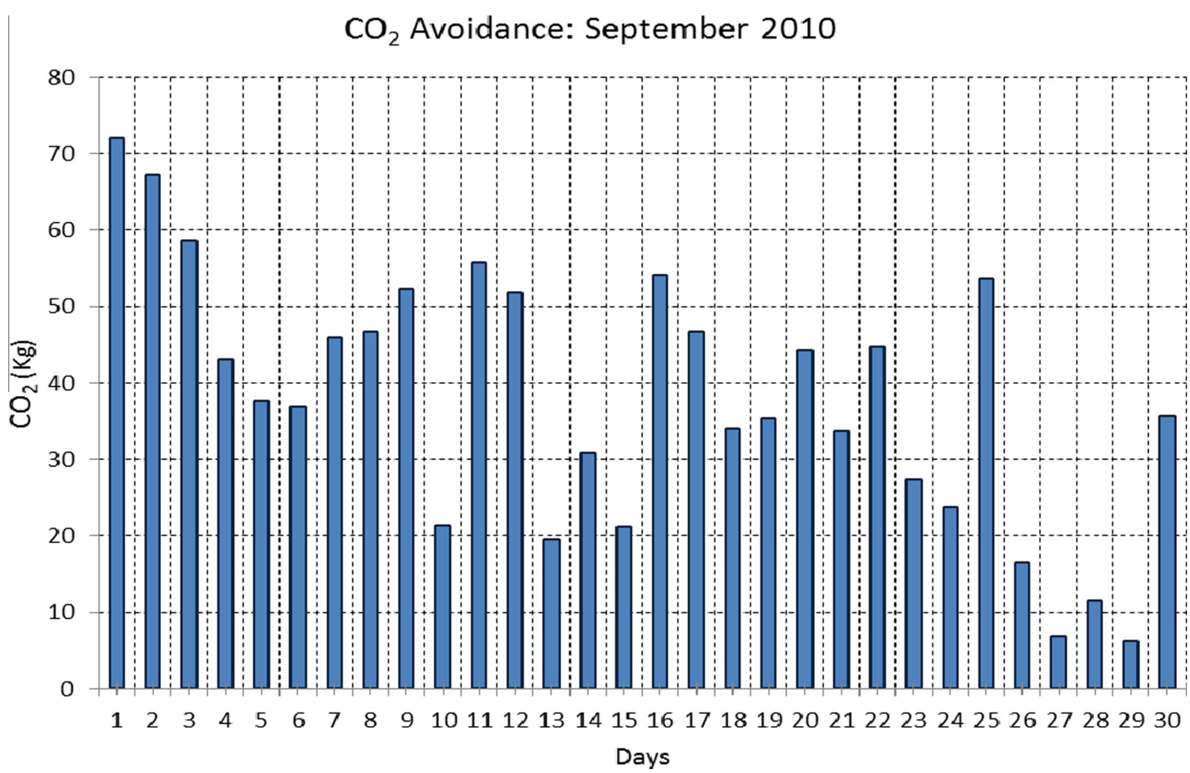

Fig. 3.3. CO_2 avoidance – September 2010.

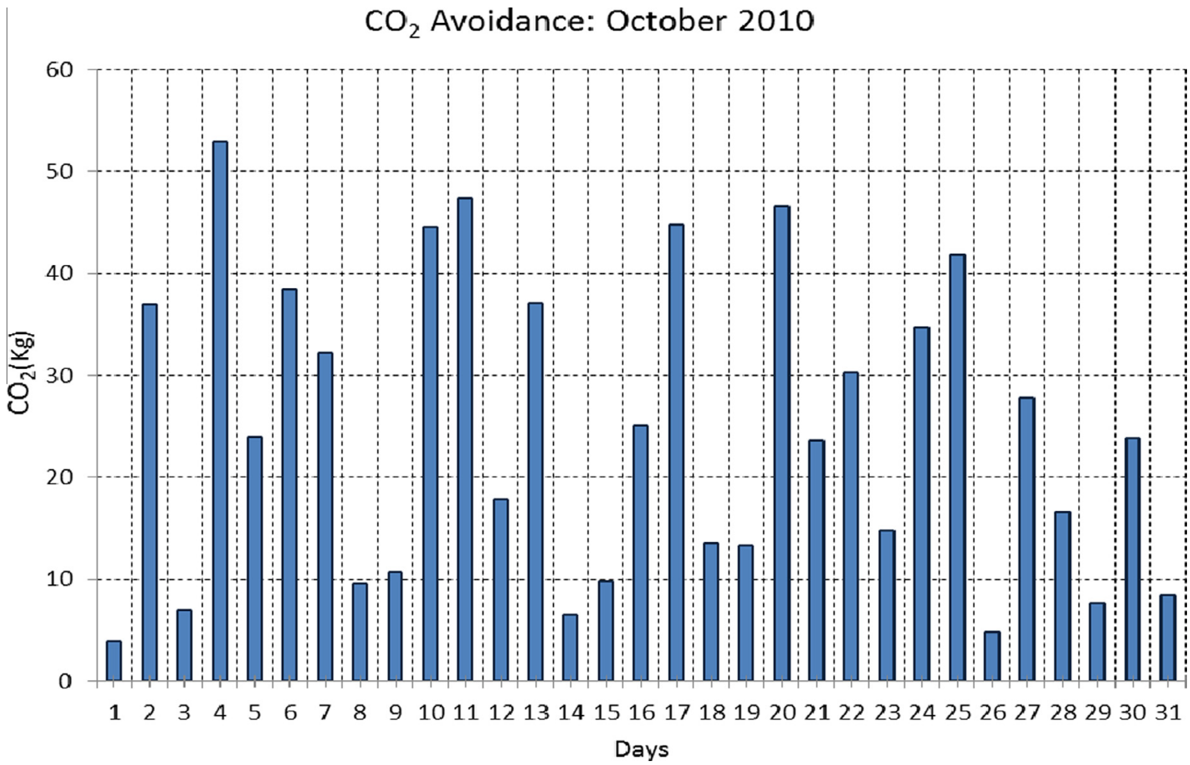

Fig. 3.4. CO_2 avoidance – October 2010.

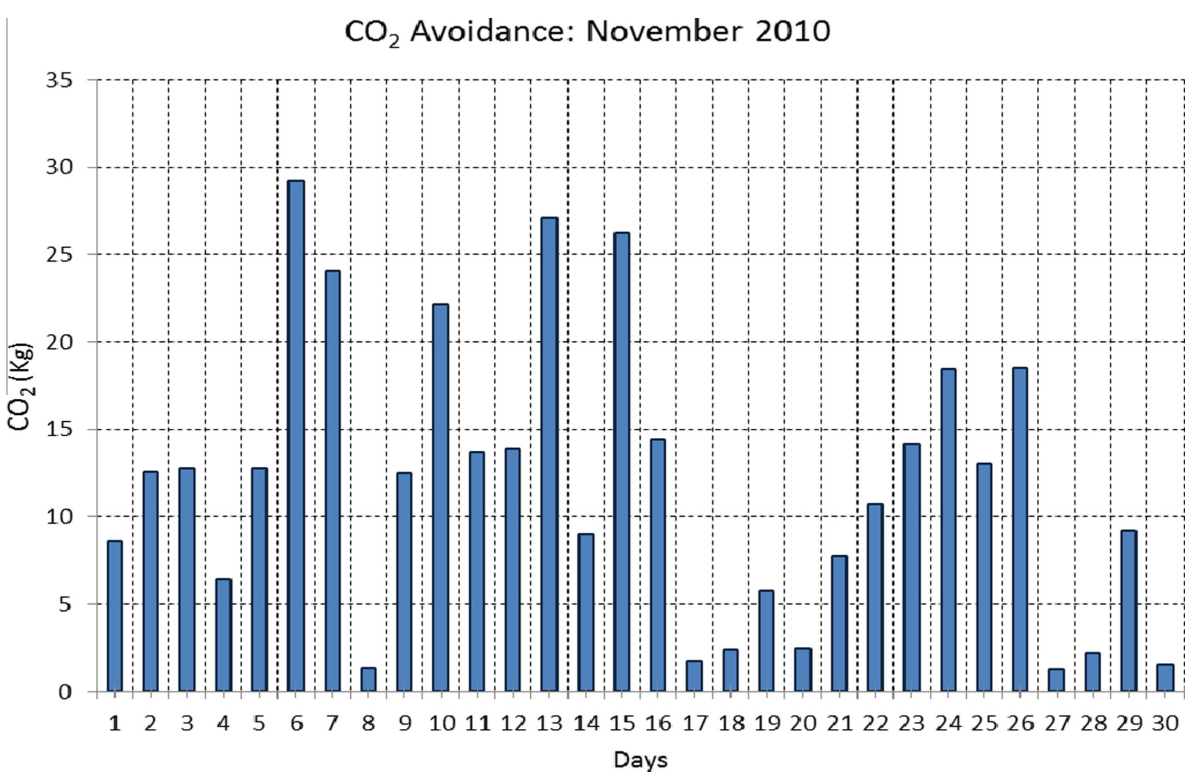

Fig. 3.5. CO_2 avoidance – November 2010.

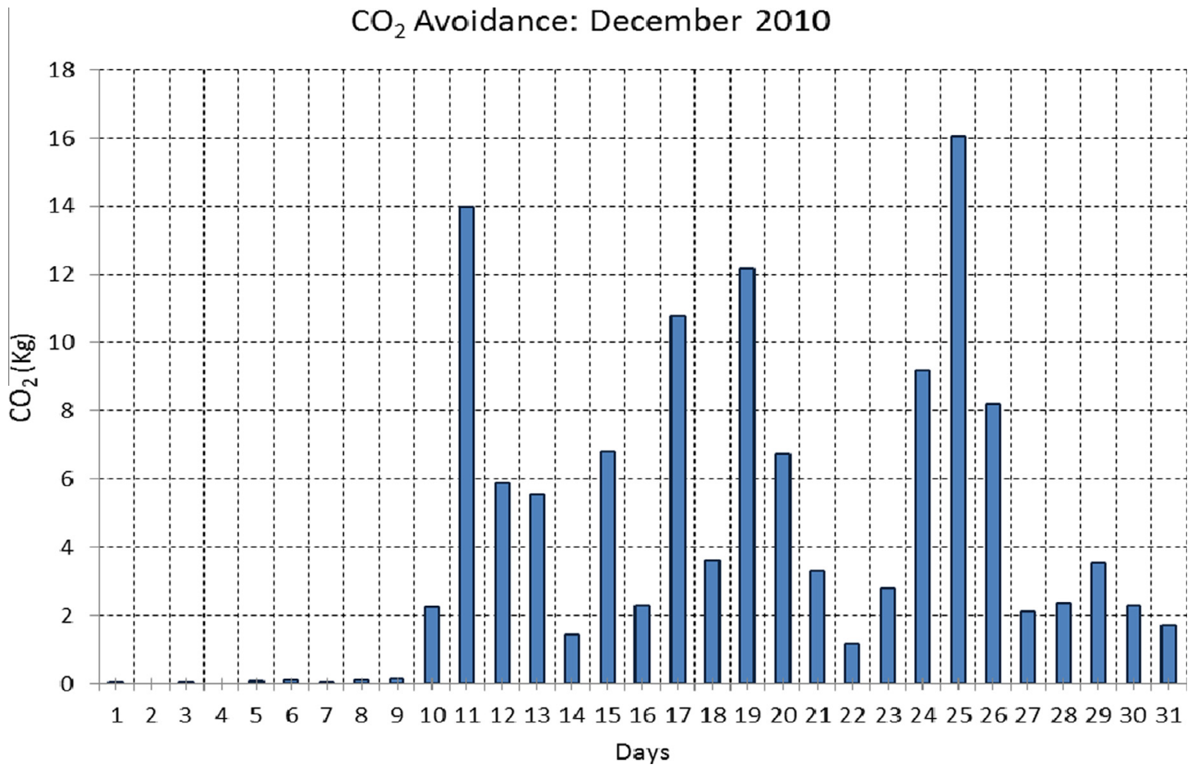

Fig. 3.6. CO_2 avoidance – December 2010.

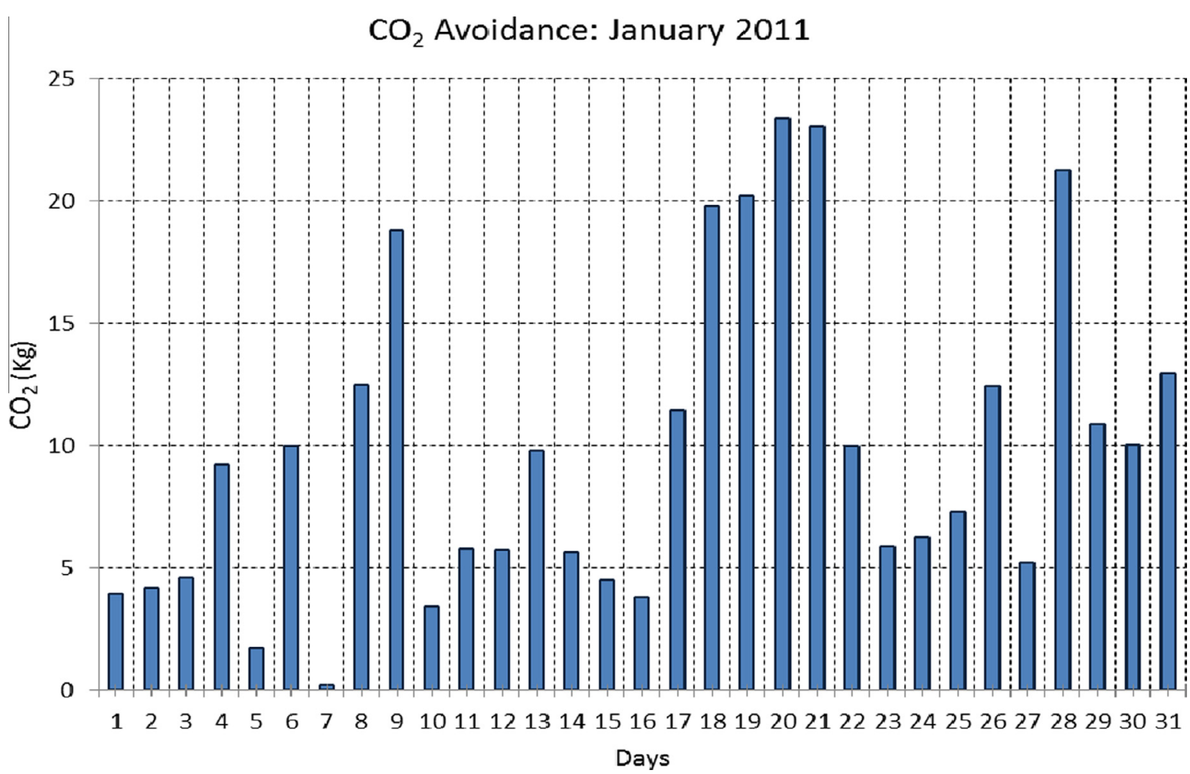

Fig. 3.7. CO_2 avoidance – January 2011.

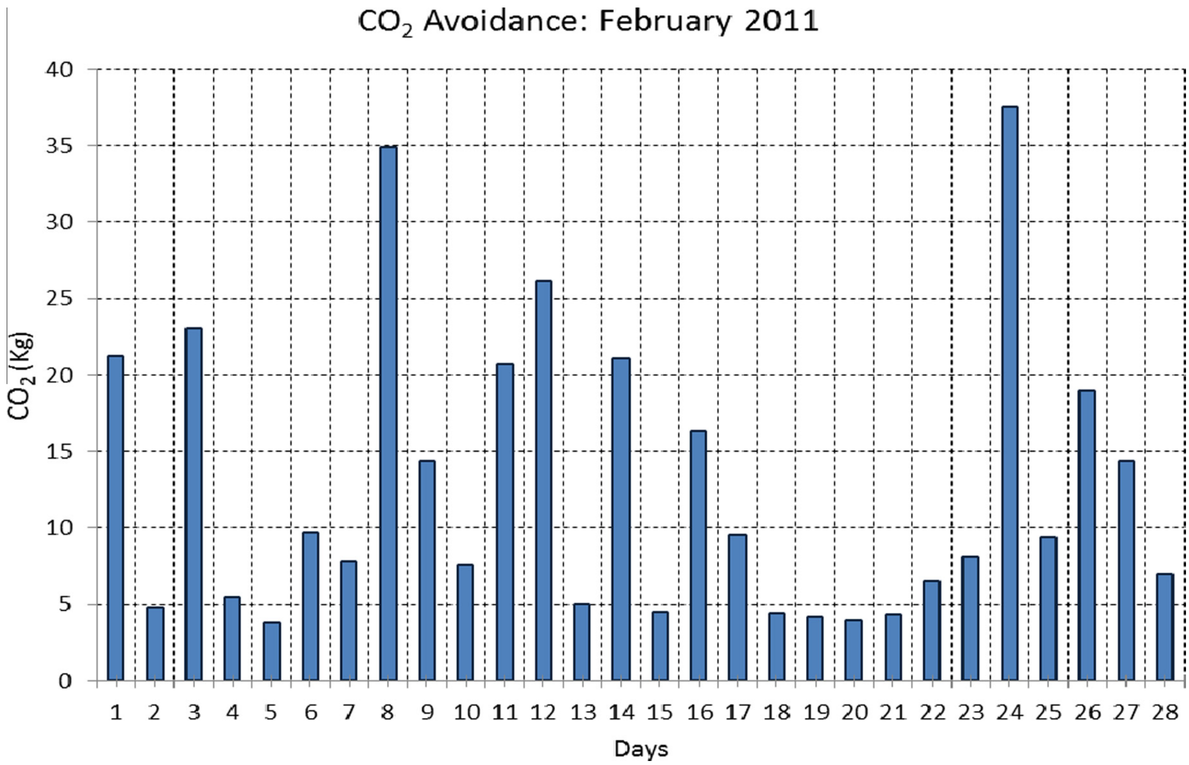

Fig. 3.8. CO_2 avoidance – February 2011.

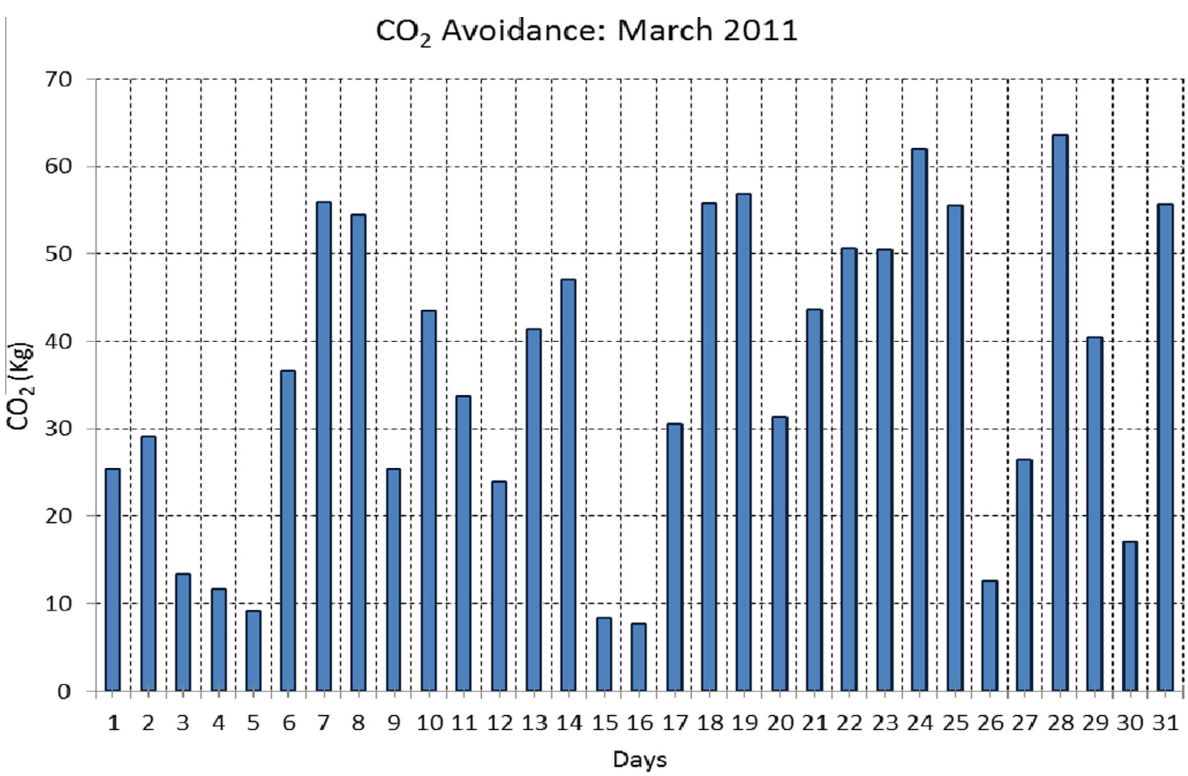

Fig. 3.9. CO_2 avoidance – March 2011.

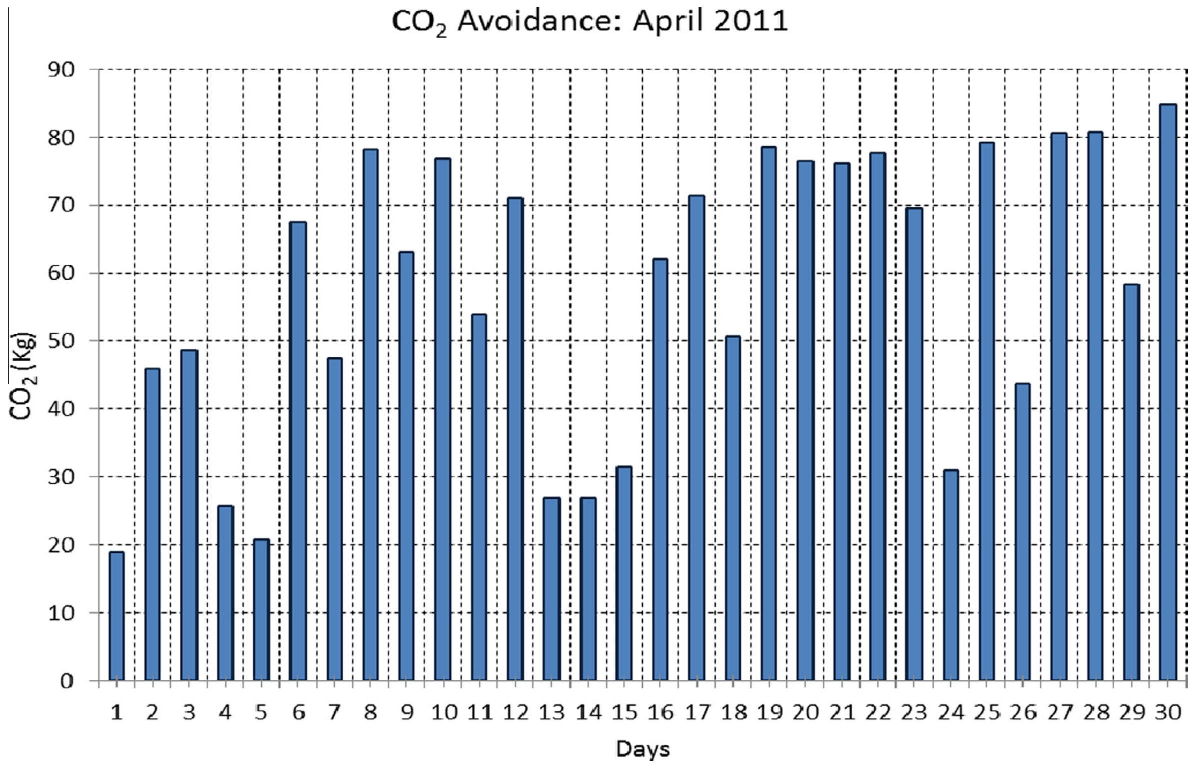

Fig. 3.10. CO_2 avoidance – April 2011.

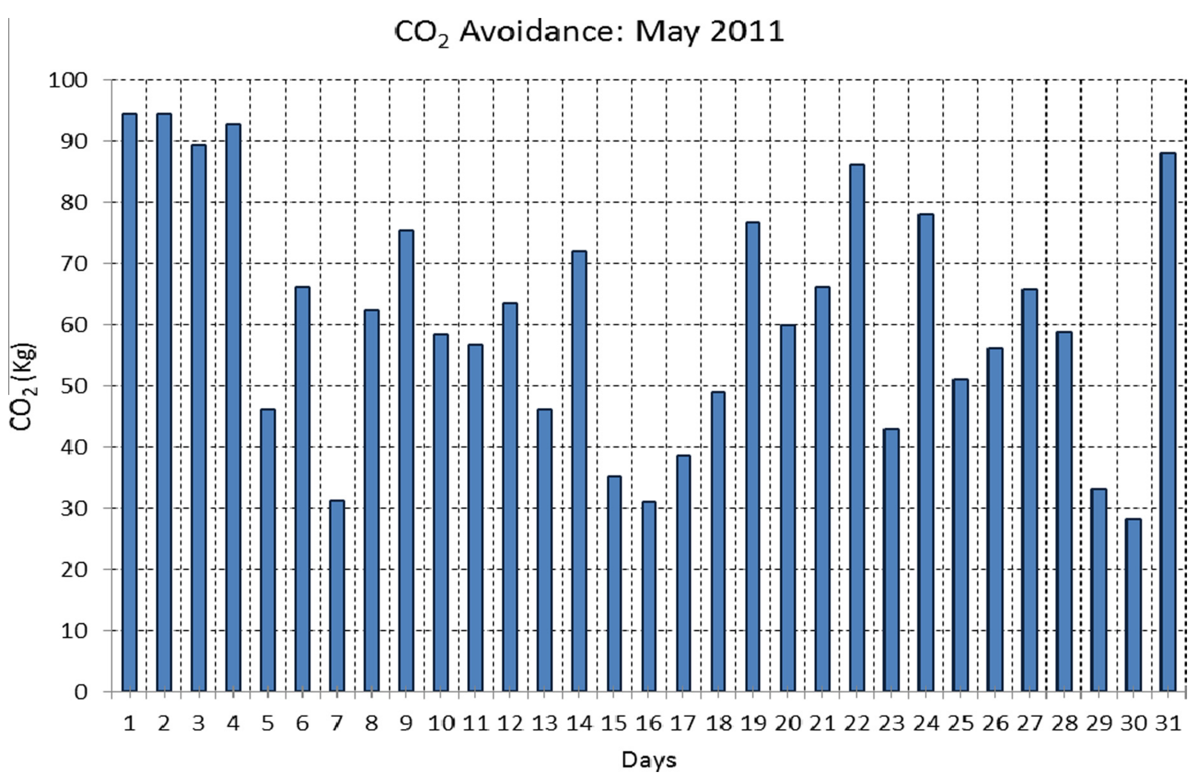

Fig. 3.11. CO_2 avoidance – May 2011.

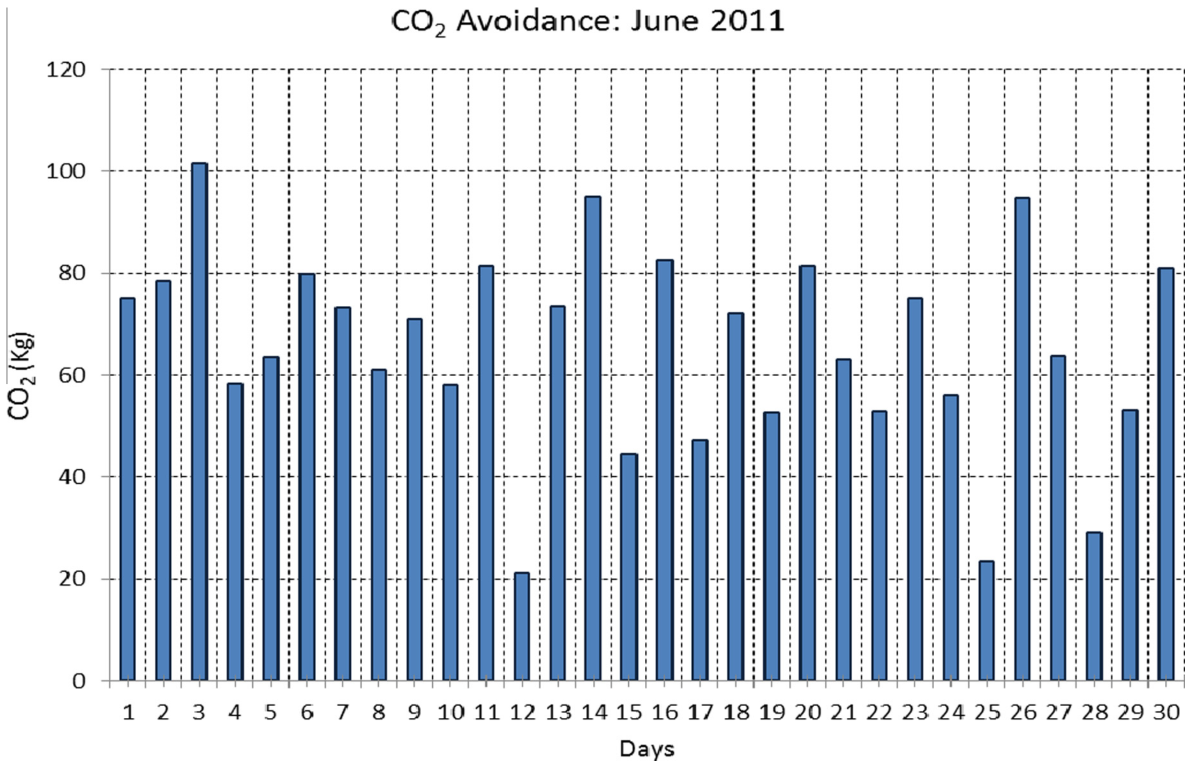

Fig. 3.12. CO_2 avoidance – June 2011.

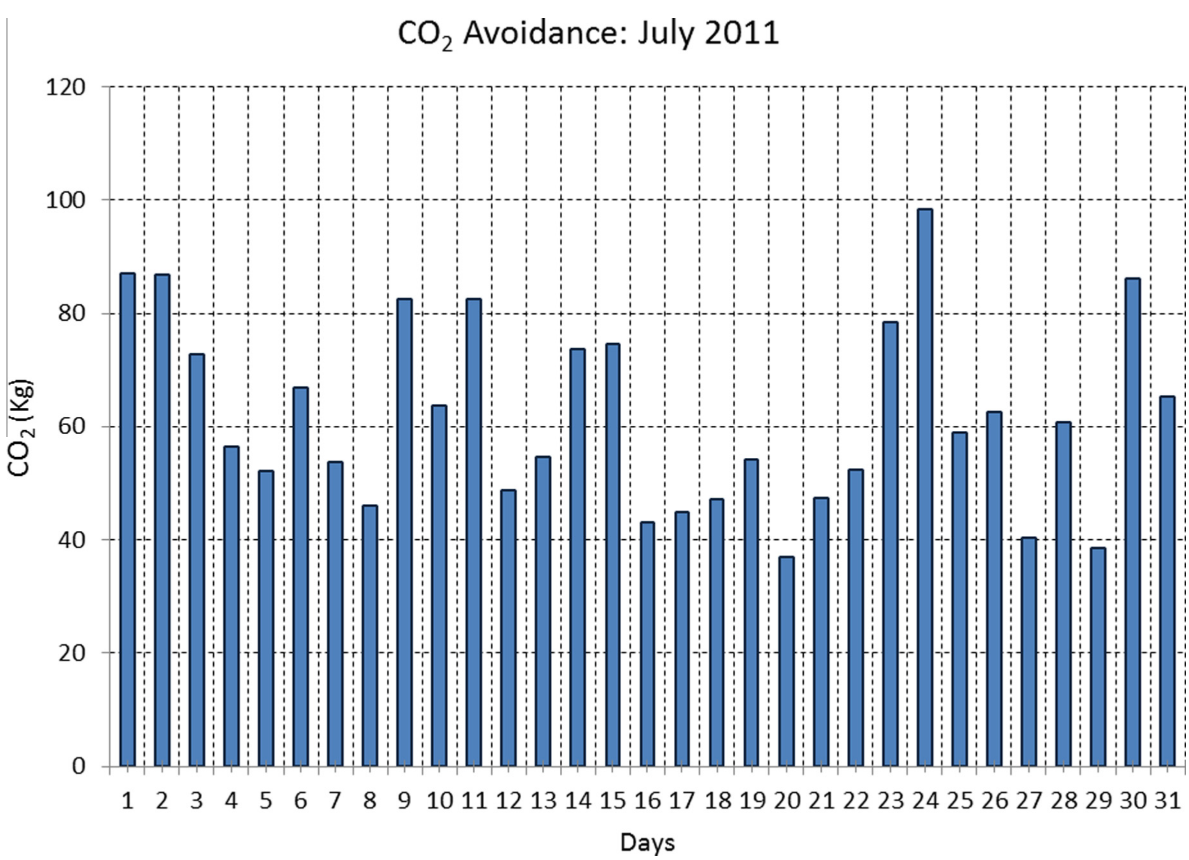

Fig. 3.13. CO_2 avoidance – July 2011.

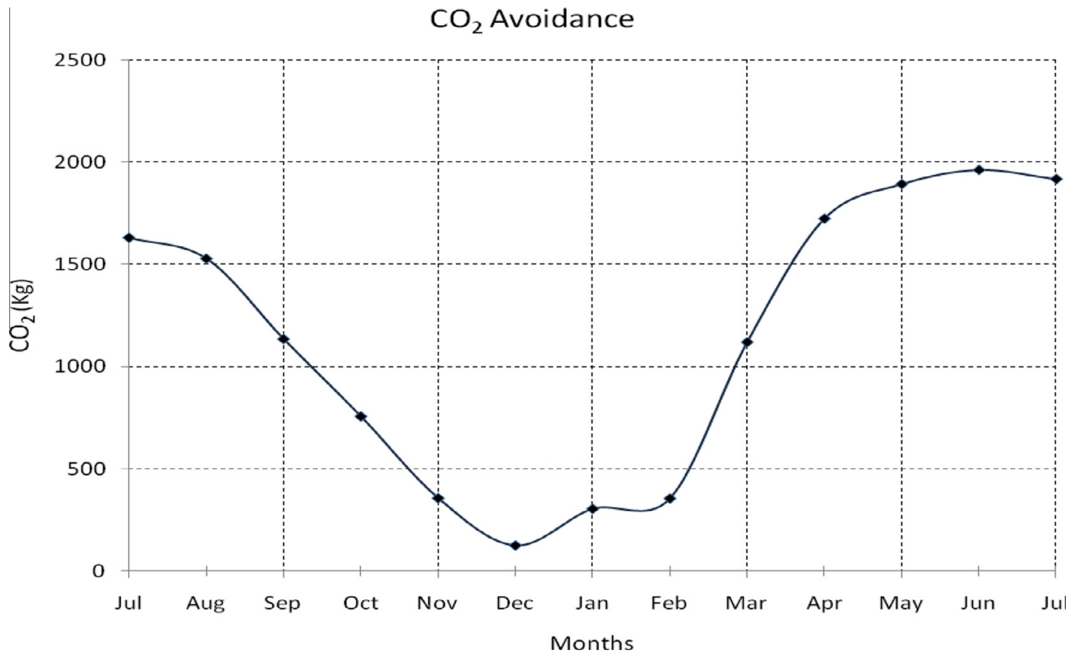

Fig. 4.0. Monthly CO_2 avoidance (University of Derby).

Fig. 3.6 shows that the system could not provide meaningful protection to the environment in the form of CO_2 avoidance from the 1st to the 9th of December 2010.

During this period, the system recorded the least CO_2 savings of about 0.1 kg up to about 9 consecutive days. The highest daily CO_2 savings of about 102 kg was recorded from the system on the 3rd of June 2011.

6. Environmental impact assessment

Fig. 4.0 below shows the monthly graphical results of the one year monitoring and evaluations from the 1st of June 2010 to the 31st of July 2011. The graph (Fig. 4.0) is a measure of the contribution of the system to climatic and environmental protection in the mitigation or avoidance of greenhouse and carbon dioxide emissions during the generation of equivalent amount of electrical power via burning of fossil fuels in the grid power station which supplies the applied building.

Figs. 3.1–3.13 are the daily results of the CO_2 avoidance, while Fig. 4.0 is the result of the monthly total CO_2 avoidance. Tables 1.0 and 2.0 below show the recorded values for the monthly total CO_2 avoidance at winter and summer seasons respectively. Based on the calibration format for the CO_2 factor in the SMA data monitoring equipment used for the study, the following measurements were recorded for the monitoring period between the 1st of July 2010 and 31st of July 2011 (Tables 1.0 and 2.0).

From Tables 1.0 and 2.0,

Total CO_2 avoidance in winter = **3,014.53 kg.**
Total CO_2 avoidance in summer = **9,873.39 kg.**
Total annual CO_2 avoidance = **12,887.92 kg.**

Table 1.0
Environmental impact of BIPV in winter season.

Month	Oct	Nov	Dec	Jan	Feb	Mar
CO_2 (kg)	756.03	356.02	124.73	303.62	354.42	1119.71

Table 2.0
Environmental impact of BIPV in summer season.

Month	Apr	May	Jun	Jul	Aug	Sep
CO_2 (kg)	1724.13	1893.00	1962.24	1630.73	1528.48	1134.81

7. Conclusion

In terms of environmental protection, the integrated solar electric generator has shown maximum performance in the summer period with a total annual environmental protection capacity of up to 12,887.92 kg of carbon dioxide.

Furthermore, it can be seen in general, that the environmental protection ability of an applied solar electric generator in a given project is determined or influenced by particular seasons of the year with respect to characteristic conditions of solar radiation obtainable at the project site.

Preliminary or pilot project designs should therefore be best conducted based on the worst months of the seasons of the year particularly cloudy periods. The essence of this is to ensure that the post commission environmental or CO_2 protection performance of applied solar generator projects does not operate below proposed expectations.

References

Ackerman, F., Stanton, E., 2006. Climate change – the cost of inaction. In: GDAE Working Paper 06-05. GDAE, Tuft University, Medford, MA.

Barlow, Stuart, Fiala, 2007. Occupant comfort in UK offices – How adaptive comfort theories might influence future low energy office refurbishment strategies. Energy Build. 39, 837–846.

Davies, R., 2005. Green Value – Green Buildings, Growing Assets. Royal Institute of Chartered Surveyors.

Perez-Lombard, Luis, Ortiz, J., Pout, C., 2007. A review of buildings energy consumption information. Energy Build. 40, 394–398.

Omer, S.A., Wilson, A., Riffat, S.B., 2003. Monitoring results of two examples of building integrated PV (BIPV) in the UK. Renewable Energy 28 (9), 1387–1399.

Tian, Wei, Wang, Y., Ren, J., Zhu, L., 2008. Effect of urban climate on building integrated photovoltaics performance. Energy Convers. Manage. 48 (1), 1–8.

Wonga, P.W., Shimodab, Y., Inouea, M., Mizunob, M., 2008. Semi-transparent PV: thermal performance, power generation, daylight modelling and energy saving potential in a residential application. Renewable Energy 33, 1024–1036.